Chapter 7
Commissioning and Start-up

7-1. Introduction

a. The objectives of the commissioning and start-up phase of a remediation system are to:

1. confirm that the system has been constructed as designed;
2. check that the equipment operates as specified;
3. facilitate making any necessary modifications in the system based on observations of site conditions that are different than expected during system installation; and
4. gather and evaluate initial operational data.

b. This chapter presents an overall strategy to follow in preparing a Start-Up Plan to carry out commissioning, shakedown, and start-up activities of an SVE or bioventing system. The system designer or operator preparing this plan is encouraged to keep in mind that each individual SVE/BV system is different and therefore may require a greater (or lesser) degree of attention than is described here for the average system. In any case, a start-up plan (or procedure) should be prepared that takes into account the system's design objectives and complexity. The plan should include:

- checklists listing each component or parameter that will be tested (samples are provided in this chapter);
- the minimum number of hours that each system, operation or parameter should be tested; and
- how each component or system should be tested (i.e., what measurements should be made).

At the end of the start-up phase, the entire SVE or bioventing system should be capable of being handed over to the owner or operator and be able to operate normally according to specifications.

c. SVE/BV systems are often implemented at sites contaminated with gasoline and diesel range hydrocarbons. In these sites especially, the Site Safety and Health Plan (SSHP) for the start-up activities must make provisions for safety monitoring relative to flammable materials. Start-up is typically the time when the highest concentrations of VOCs are present in the soil pores. These concentrated vapors may either be extracted by SVE systems or "pushed" by injection systems into adjacent areas, and may exceed the concentration deemed to be acceptable (i.e., may approach the lower explosive limit (LEL), and eventually create explosive conditions). Combustible atmospheres must not be allowed to develop or must be carefully controlled if they do exist. Flame ionization detectors (FIDs), tuned to the appropriate hydrocarbon product or component, should be employed. Combustible gas indicators (CGIs) may also be used, but only if oxygen levels are also being monitored. CGIs can produce false readings if the level of oxygen falls below the minimum level required for the instrument to function properly. For other compounds, such as nonflammable chlorinated solvents, field monitoring devices should be used to evaluate any health and safety concerns that may arise from a leak or failure during the start-up of the system. At this point in the planning process, the procurement of any required air emission or water discharge permits should be completed or underway.

7-2. Collection of Baseline Data

a. In order to evaluate the operation of the SVE/Bioventing system and the future progress of the remediation, data describing subsurface conditions collected during operation will be compared to data describing subsurface conditions before remediation began. Since the operation of the system may affect many of these conditions semi-permanently, it is critical that such baseline data be collected prior to start-up. Much of the necessary baseline data will have been collected as part of the site characterization (see Chapter 3) or during pilot testing activities needed to design the SVE/BV system (see Chapter 4). However, these data might not have been collected extensively enough across the site or recently enough to describe conditions prior to initiating remediation. Therefore, the start-up plan should begin with a review of the existing baseline site data and provision for collection of any “missing” data.

(1) To help in the evaluation, planning and gathering of baseline data, Table 7-1, Baseline Data Checklist, should be reviewed in detail. It lists the data that should be collected and analyzed before start-up of the system. As with any sampling, analysis and monitoring program, a site specific and specialized Baseline Monitoring Sampling and Analytical Plan (SAP) should be prepared that specifies:

- the type and number of samples and/or baseline parameters to be collected;
- methods of data collection;
- sample and measurement locations;
- the analytical methods; and
- QA/QC requirements.

b. If the remediation strategy totally or partially relies on bioventing, biological indicators such as counts of hydrocarbon-degrading bacteria, carbon dioxide and oxygen measured in subsurface probes and in extracted soil gas should be part of the SAP. To ensure project efficiency and consistency, this SAP should be prepared in a comprehensive manner so that it will also control the sampling and analyses during the start-up and operations and maintenance phases of the remediation.

Table 7-1
Baseline Data Checklist

Checklist Item	Responsible	Initials	Completion Date	Comments
Vadose zone gaseous methane, carbon dioxide and oxygen concentration variations				
Vadose zone oxygen demand (for bioventing systems)				
Vadose zone soil samples: contaminant concentrations, and moisture content				
Vadose zone soil gas VOC concentrations (SVE wells and monitoring points)				
Bacteria enumeration in soil and/or groundwater (optional), and nutrient levels in vadose zone (optional)				
Groundwater levels without applied vacuum				
“natural’ variation (if any) soil gas pressure under different atmospheric pressure conditions				
Frequency and Data “quantity (how many locations, etc.)” = depends on how recently such data was collected as *part of the site investigations, site size, budget, clean-up levels, etc.*				

7-3. Equipment Shakedown and Testing

a. The shakedown and testing process is comprised of three primary activities:

- Pre-commissioning check;
- Functional performance tests of individual components;
- Pre-start-up, functional performance system testing of the combined components (including actual soil vapor extraction or bioventing as warranted to test the system).

This section will discuss these closely related phases. Section 7-4 will present guidance on the actual start-up and demonstration of the operation of system(s) before handing over the system to the O&M contractor. The checklists shown in Table 7-2 and 7-3 are adapted from USACE Guide Specification 01810, Commissioning and Demonstration for Soil Vapor Extraction Systems.

(1) Pre-commissioning checkout. This is an inspection to verify that all the components of the system, below and aboveground, have been properly installed. A checklist for these pre-commissioning activities and functional performance component testing is presented in Table 7-2. The commissioning tests should be performed according to the agency’s protocols or the system start-up plan. Any deficiencies must be corrected and retested to meet contractual or technical requirements. The pre-commissioning checklist is a working document that allows the system installer and evaluator to assess if an aspect of the system meets requirements (MR), or requires further action (AN). If further action is needed the team (or Contracting

Officer) determines what action, when it will be completed by, and who is responsible. The checklist will be initialed by the appropriate team member at completion and acceptance of a particular item.

(2) Any building foundations should be checked to verify that they were placed properly, sealed properly (if they are coated for containment reasons), and protected from damage while curing. Some equipment can be sensitive to level, particularly if it has level controls, weirs, or baffles designed to skim, separate, or otherwise control liquids in the system.

(3) The system's piping and instrumentation (P&I) diagram is the best document to use to verify that all equipment and piping are installed as designed. As-built drawings should also be created and updated as necessary. Electrical systems should be checked to verify that wiring has been completed correctly and according to the applicable code(s). The electrical One-Line Diagrams and Wiring Diagrams are good documents to use to verify electrical and instrumentation systems. Protective covers on rotating equipment should be in place. This is also the time to verify that all the required equipment specified in the SSHP, as well as equipment lockouts, safety valves and/or other pressure relief devices, and site security devices are properly installed.

b. Functional performance tests of individual components. The equipment functional performance tests should only commence after all the pre-commissioning checks have been performed successfully. Table 7-2 contains suggested equipment tests that should be considered for listing in a specific checklist prepared for the startup of the system. The equipment functional performance tests should be carried out in a manner to duplicate the vendor's recommended procedures. If no vendor procedures are provided, performance test methods must be developed to meet the information needs specified in the checklist. These tests should be consistent with the detailed procedures for operating all the equipment to be included either in the site-specific operating manual or the SSHP. If the aboveground system has been assembled elsewhere, some of these tests can be carried out before the system is transported and installed on-site.

c. Pre-start-up, functional performance system testing (of the combined, above ground components). After the pre-commissioning checks and individual component testing has been successfully completed, the testing of the entire system is performed to verify integrity prior to actual operation. The functional performance testing begins with subsystems and ends with the complete remediation system passing its performance specifications and contractual requirements testing. Any deficiencies with the system must be corrected and performance checks successfully completed before the system can be accepted.

(1) The checklist in Table 7-2 also includes the testing that needs to be done in this system performance test phase. Once the equipment and electrical systems are tested and certified ready for operation, electrical systems can be powered up in preparation for testing equipment and control systems. Analog controls are electrically tested with signal generators to verify operating ranges. Where controls provide ON/OFF signals, switches can be manually tripped to test control loops. Testing of control systems should proceed from this point to verify operability. If there are safety shutdown sequences in the control systems, they should be tested to be sure they are installed and functioning properly. Motors that can be started with hand switches should be turned on to test rotation of rotating equipment. All interlocks, motor starters controlled by interlocks or a PLC (programmable logic controller) and other relationships between equipment should be tested to determine if the responses are consistent with the design logic.

Table 7-2
Suggested SVE/BV Pre-Commissioning Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Wells							
Wells/trenches installed per specification (depth, size, etc.)							
Vadose and/or groundwater monitoring points installed and capped							
Wells/monitoring points surveyed							
Temperature, vacuum / pressure gauges installed on wellheads and monitoring points							
Piping Installation							
Piping and piping supports complete (including from wells/trenches)							
Piping flushed/cleaned							
Strainers/filters installed/cleaned							
Valves installed and operation verified							
Insulation/heat tape installed							
Thermometers, sampling ports, monitoring ports and vacuum / pressure gauges installed on wells or piping							
Pressure, vacuum or liquid leak test complete (except for joints that have to be tested while the blower is operating)							

*NA = Not Applicable
MR = Meets Requirements
AN = Action Needed

Table 7-2
Suggested SVE/BV Pre-Commissioning Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Air / Water Separator							
Leak testing complete							
Valves installed as required							
Operation of valves verified							
Piping labeled and valves identified as required							
Condensate drainage is unobstructed							
Pumps / Blowers							
Vibration isolation devices installed as specified							
Casing and silencers undamaged							
Where rotating equipment requires initial lubrication, check to ensure that manufacturer's procedures have been followed.							
Proper belt tension, if belt driven							
Protective covers on rotating equipment in place							
Manufacturer's required maintenance clearance provided							
Pump rotation verified							
Pressure / temperature gauges installed							
Silencers and sound proofing installed							
Coupling alignment/level to specifications							

Table 7-2
Suggested SVE/BV Pre-Commissioning Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Pipe connections installed/tested							
Pressure / temperature gauges installed							
Air cooling equipment properly installed, for cooling blower exhaust (if used)							
Spare inlet air filter present on-site							
Pumps and seals intact (no leaks)							
Electrical							
Continuity checks performed to verify wiring loops.							
Protective covers on terminal boxes and panels in place.							
Power available to unit disconnect							
Power disconnect is located within sight of the unit it controls							
Grounding installed/checked							
Lighting and HVAC functional							
Lockouts on panels/switches installed							
Wiring integrity between components and supply (no damage or deterioration)							

*NA = Not Applicable
MR = Meets Requirements
AN = Action Needed

Table 7-2
Suggested SVE/BV Pre-Commissioning Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Instrumentation and Control							
As-build shop drawings submitted, and controls match shop drawings							
Panel components properly labeled							
Control components piped or wired to each labeled terminal strip							
Control wiring and tubing labeled at terminations, splices, and junctions							
Shielded wiring used on electronic sensors							
Power connected to instrumentation							
Valves (air bleed, dilution, and check) installed and operation verified							
Temperature, vacuum and pressure gauges installed and calibrated over proper ranges							
Individual control, alarms and interlocks functional							
Instrumentation and control (PLC) system operational							
Telemonitoring system/modem operational							
On-line gas analysis instruments functioning and calibrated							
On-line gas or liquid flow devices functioning and calibrated							
Vapor Stream Treatment System							
Verify status of air pollution control permit (if required)							

Table 7-2
Suggested SVE/BV Pre-Commissioning Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Verify use of flexible lines and connectors for changing position of lead, lag, and spare activated carbon vessels (if used)							
Spare activated carbon vessel on-site, if required							
Flame arrestor properly installed on vapor oxidizer (if used)							
Auxiliary fuel feed operational (if used)							
Ancillary Equipment							
Field monitoring instruments calibrated							
Control panel purge system operational (if used)							
Liquid ring fluid system functional (if needed)							

*NA = Not Applicable
MR = Meets Requirements
AN = Action Needed

(2) Care should be taken at this point to be sure that process flow equipment (such as pumps and blowers) are only tested for short periods and not run long enough to damage the equipment running “dry”. In fact, some equipment will not be able to be tested without actually extracting soil gas from the subsurface. For such equipment, short testing periods (say, up to 30 minutes) should not impact the subsurface conditions to such a degree that would invalidate the formal startup described below. After all systems have been tested and certified for operation, the entire facility should be cleaned of dirt, dust, and liquids on, under, or around the equipment. At this point, systems should be considered ready for actual operating tests (start-up).

7-4. System Start-Up/Full-Scale Demonstration

During the start-up phase, the entire remediation system is operated and remediation actually commences. The strategy for start-up is to conduct these activities sequentially, comparing observations and test data against design and performance criteria. This will allow the system to be brought on line in a systematic and safe manner to meet the operational objectives. The sequence terminates when the design and equipment performance is documented to comply with specifications, and the system is ready for transition into the operations and maintenance phase. The start-up plan may state a minimum number of operating hours with a minimal percentage downtime before the owner will accept the system.

a. This guidance section is divided into three sections that overlap and must be planned together: operations, subsurface monitoring, and aboveground system monitoring. Table 7-3 provides a checklist to assist in preparing a similar Functional Performance Checklist for this start-up phase. This table contains suggested equipment tests that should be considered for listing in a specific checklist prepared for the startup of the system. Data should be collected on field data collection forms as well as keeping a log of all observations. It is particularly important to note any changes that are made in the system that alter the original design or operating instructions. Individual offices should develop similar forms which meet their specific system and site needs. A few comments are in order to place the checklists in perspective:

(1) Even when a system has been designed based on a pilot test, the soil conditions at many sites may present unexpected conditions. Soil heterogeneities across the treatment area may present conditions under which a specific design point (e.g., flow rate at a specified vacuum) cannot be reached because soil conditions will not permit it (e.g., due to non-uniform soil permeability). In these cases, the pump curve for the specified equipment will need to be consulted to verify that the actual operating point is on the same curve as the design point. This may also affect air treatment equipment and flow measurement devices.

(2) Some sites which are amenable to SVE/BV treatment are relatively simple in design and hence in start-up requirements (i.e., treatment of a single contaminant in homogeneous soil with no water table impact). In this case, not all of the checklist items will be necessary, but acknowledgement using N/A will indicate that the item has at least been considered.

(3) At the very end of the start-up period, the commissioning team implements the checklists as part of a two-level start-up procedure. The team will typically consist of a member of the contracting staff; a member from the Contracting Officer's staff; the contractor, and the using entity (often from the base environmental staff). Subcontractors may be represented for specific parts of the start-up involving subcontractor equipment. The commissioning team will assign responsibilities for each of the checklist items among the team members. The checklist is a working document that allows the commissioning team to assess if an aspect of the system meets requirements (MR), or requires further action (AN). If further

action is needed the team (or Contracting Officer) determines what action, when it will be completed by, and who is responsible. The checklist will be initialed by the appropriate team member at completion and acceptance of a particular item.

b. Operational. The start-up procedure will be different for each particular system configuration. In all cases, start-up of an SVE or BV system should proceed slowly with a well-planned sequence of events. This is especially important when toxic or flammable materials are to be processed through the system. All related health and safety and emergency response procedures and issues should be in place and reviewed before this phase of operation. Pieces of equipment that can be operated without process liquids or vapors should be started first. For example, sump pumps can usually be put in service independent of most other components. Where there is a need for compressed air (either utility or instrument air), an air compressor can be put in service first. Control systems must be energized before process equipment is started. Again, system configuration influence what can operate and what cannot operate without process fluids present. All equipment to be on stand-by during full operation should be started before process equipment is started.

(1) Before process systems are started, make a final check on the position of all valves and control set points. Start the SVE system without extracting soil vapor by either closing the main manifold valve to the SVE wells, by setting the pressure controls for minimum applied vacuum, and by opening the inlet bleed-valve to the ambient air. BV systems should be started with the bleed-off valves open (so air is diverted away from the injection wells). With systems using thermal oxidation, start with auxiliary fuels to heat the systems before extraction gas is introduced into the unit. Then increase the vacuum applied to the SVE wells incrementally to start extracting small flows of soil vapor and so that periodic inspection of the entire system can be made to ensure proper operation. If BV or re-injection systems are used, begin with low pressure and increase the pressure step-wise as the vacuum system flow rate is increased. Monitor the influent to an oxidation system to confirm that potentially flammable or explosive levels (15% LEL – lower explosive limit is often chosen as a cut-off point) that could damage the system are not present (most oxidation systems have self monitoring controls that prevent this from happening). Monitor the exhaust from any vapor treatment system to confirm that it is operating properly and so that emission limits are not exceeded. For BV systems, vapor monitoring may be required in nearby basements and utility corridors. Observations, sampling, and other performance testing (as described in the next two sections) can be performed during start-up to ensure that the system is operating as expected.

(2) Once the system is running at or close to the expected operating conditions, the entire system should be checked. Check the flow, pressure, and temperature at each extraction well and the operation flows, pressures, and temperatures at all monitoring points in the system (as described in the following section). Oxygen levels at monitoring points should measured for bioventing systems. Compare operating data with equipment performance data for discrepancies. Note that systems may take time to stabilize. Some may reach equilibrium in a few minutes while others may take a day or two. The aboveground systems will reach equilibrium much more rapidly than the subsurface systems. But as subsurface systems stabilize, aboveground systems may change too.

(3) Soon after an SVE system is started, check for condensate accumulation. Check to see that the condensate removal and/or treatment systems are operating correctly. Look for evidence of condensate accumulating in piping, and check low-point drains.

(4) The sustainable discharge concentration may be manipulated to some extent by deliberately inducing airflow through the most concentrated areas of VOCs. The sustainable discharge should be maintained as high as possible balancing airflows to maximize the concentration, and/or VOC removal rates. The system balance should be checked periodically throughout the remediation program (initially every 2 weeks) to ensure that the optimum balance is re-determined, as the concentrations will change over time.

Table 7-3
Suggested SVE/BV Startup and Functional Performance Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Subsurface							
SVE well specific capacity within expected ranges							
Groundwater level rise during SVE within expected ranges							
Vacuum levels at SVE wells and vadose zone monitoring points within expected ranges							
Assess adequacy of vadose zone air flow rates							
Contaminant level at vadose zone monitoring point within expected ranges (if measured)							
Oxygen and carbon dioxide levels at vadose zone monitoring points responding to BV / SVE as expected							
Piping, Valves and Instrumentation							
As wells are valved on, leak-test joints not previously tested. Repair until leaks are eliminated							
Check for water at drainage points							
Verify operation of heat tracing							

Table 7-3
Suggested SVE/BV Startup and Functional Performance Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Monitoring systems/instruments hold calibration							
Independent measurement of air flow rates by Contractor and Testing, Adjusting, and Balancing (TAB) specialist. Results differ by no more than 10%							
Air / Water Separator							
Check pressure drop across unit							
Compare airflow rate and pressure drop against manufacturer's specifications							
Check water level via sight glass, or other indicator							
Check operation of condensate drain valve							
Check setting of high-level alarm in condensate collection vessel							
Pumps / Blowers							
Start/stop functioning from all control mechanisms							
Blower speed (rpm) meets manufacturer's specifications							
Current draw and voltage balance match specifications for all phases							
Temperature at inlet and outlet of unit meet manufacturer's specifications							
Liquid ring fluid subsystem functions properly (if used)							

Table 7-3
Suggested SVE/BV Startup and Functional Performance Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Verify operation of variable speed (if used)							
Verify settings of vacuum relief valve, pressure relief valve, and high-temperature shutdown							
Plot readings of pressure and airflow rate on graph, and compare to manufacturer's specifications							
Measure noise level and note any unusual vibrations or noises							
System Controls							
Verify that controllers maintain set points by manually measuring the controlled variable with thermometer, differential pressure gauge, or other device							
Verify that interlocks function according to specifications, and in concert with other system controls							
Verify that control system conforms to that specified in the sequence of operation							

*NA = Not Applicable
MR = Meets Requirements
AN = Action Needed

Table 7-3
Suggested SVE/BV Startup and Functional Performance Checklist

Checklist Item	NA*	MR	AN	Action	Initials	Completion Date	Comments
Vapor Stream Treatment System							
Leak-test joints not previously tested. Repair until leaks are eliminated							
Measure air flow rates at inlet and outlet							
Measure temperature and pressure across lead and lag vessel (if used), and compare to manufacturer's specifications							
Catalytic oxidation system, and fuel feed subsystem, operate within specifications (If used)							
Measure organic vapor level at inlet and outlet of system							
Soil vapor treatment system performance meets removal efficiency requirements and emission concentration limits							

*NA = Not Applicable
MR = Meets Requirements
AN = Action Needed

c. Monitoring of Subsurface Conditions

Field measurements are conducted on a routine basis in order to monitor the efficiency of the SVE/BV system. Of particular concern during start-up is whether a SVE well's operating conditions are very different than those assumed during design. Many wells will be turned on for the first time during start-up, if earlier wells were pilot tested and used for design. Questions to consider include the following: Does a particular well produce the expected flow for the applied vacuum? Are vapor contaminants in the extracted soil gas at the expected concentration? Are surrounding soil gas vacuums as expected? How significantly does the applied vacuum drop in the SVE well sand or gravel pack around the well? Start-up provides the first opportunity to check design assumptions.

(1) Groundwater level measurements. Groundwater level measurements are required to evaluate the effects of the applied vacuum on water table upwelling and the subsequent effect of water table upwelling on system performance. Water table upwelling can submerge contaminated soils near the water table, rendering them inaccessible to vapor flow and therefore “unremediated”. Water table upwelling also reduces the thickness of unsaturated soil near individual vents, limiting the available airflow. This usually occurs in only a localized area around each SVE well. The effects of water table upwelling can be reduced by lowering the applied vacuum, installing additional extraction vents, installing dilution air inlet vents, and/or by dewatering.

(a) The amount of water table upwelling at any point is equal to the original water table elevation plus the magnitude of the applied vacuum (in centimeters of water) (see paragraph 3-2d). Direct measurement of water table upwelling requires the wellhead to be sealed at the atmosphere to prevent loss of the applied vacuum at the time of measurement.

(b) This can be accomplished by installing a pressure transducer at a fixed elevation beneath the lowest anticipated water table within the monitoring well. The pressure transducer must be referenced to the well pressure, not atmospheric pressure, which may be greater than the air pressure in the well. Of course, care is required to ensure that no leaks are present at the measurement wellhead. Commonly, a connection with the air pressure in the well may be accomplished via an air tube built into the electrical cable. Pressure transducers of this type are usually connected to a multichannel data logger which is down-loaded at convenient intervals. Groundwater level measurement methods are also discussed in paragraph 4-5e(18).

(2) Soil vacuum or pressure measurements. Vacuum or pressure gauges installed at various locations on the SVE or BV wells, vadose zone monitoring points and the airflow manifold network are monitored during start-up so that flows and pressures can be adjusted. Johnson et al. (1990a) report that several hours to several days of system operation may be required to establish steady-state flow and vacuum conditions, depending on the air permeability of the soil. If an air permeability test has been performed prior to system design, this will have provided an indication of the amount of time needed to achieve steady-state flow. Verifying the air permeability at each extraction or injection well is also recommended. During the initial transient stage, vacuum data should be collected frequently, with the collection intervals increasing with time. For example, if electronic data loggers are used, a typical setup might collect data points every minute for the first hour, every five minutes for hours 2 through 10, every ten minutes for hours 11 through 24, and every thirty minutes thereafter. Although this should only serve as an example, the point is that the vacuum at a given radius varies logarithmically with respect to time, and as conditions approach steady-state, the vacuums will change less dramatically over a given period of time. The start-up data should be

compared with the results of the air permeability test to determine whether any flow rate or vacuum adjustments need to be made.

(a) One of the foremost considerations stemming from vacuum/pressure data during start-up is the spatial distribution of pressure around each extraction point. This is determined by measuring the soil pressure (vacuum) in vadose zone monitoring points around and between SVE wells. The sensitivity required for vacuum (or pressure) measurements in the soil usually does not exceed 0.25 cm (0.1 inch) of water. Magnehelic® gauges or water-filled manometers can provide measurements within this general range. It is also important to evaluate whether subsurface airflow rates are adequate. Whole sets of pressure (or vacuum) data must be evaluated to assess airflow rates. Some of the questions to be answered with this data include:

- Are there locations at similar distances from SVE wells exhibiting much less influence than others?
- Are there strata exhibiting substantial differences in influence from SVE wells?
- Are these findings consistent with the conceptual understanding of the site based on existing site characterization data, or do they point to unforeseen factors?

For example, in a relatively uniform sand, one might observe the same pressure drop with distance regardless of direction, consistent with isotropic conditions.

(b) A finding, however, of little or no vacuum influence in one sector might indicate the presence of some subsurface barrier to airflow, such as a buried foundation; a utility conduit enabling air to bypass one area in favor of another; or perhaps short-circuiting of airflow due to improper installation of SVE system components. Installation of additional air piezometers might be necessary to establish the cause of such a problem. Depending on the cause, the solution could involve one or more of the following: altering the spacing or screen depth of additional extraction or injection wells; using grouting or other method to retard flow through preferential pathways; or placement of a surface cover. Accordingly, periodic adjustment of flow rates or vacuums can alleviate problems presented by stagnation zones.

(3) Soil Gas Flowrates **-** Soil gas flowrates must be measured in the piping from each SVE/BV well in order to balance the flow among all the wells. Without annular stabilizing fins, the non-uniform nature of airflow in pipes typically causes variations of 15% or more in airflow velocity. The data generated with Pitot tubes (differential pressure) or hot wire anemometers (heat loss) can be used to measure velocities and thereby the flow within this general range of accuracy, which is usually sufficient for balancing flows. For more accurate readings it may be necessary to measure airflow at several pre-determined locations across the pipe cross-section (i.e., transverse readings). Instruments with multiple sensing ports and averaging capabilities are also available (e.g., transverse, averaging pitot tubes). Flow monitoring ports should be positioned in straight sections of piping, according to manufacturer's directions. For example, pitot tubes should be placed at least 8.5 pipe diameters upstream, and at least 1.5 pipe diameters downstream of elbows, restrictions or other obstructions in the piping. Velocity data can be measured periodically by portable instrumentation or continuously by a electronic control system. Rotometers are sometimes used to monitor flow, but usually the large pressure drop is not considered acceptable. All these devices need to be calibrated at an established frequency.

(4) Soil Gas Contaminant Concentrations – One of the most important parameters to measure during start-up is the concentration of VOCs in the extracted soil gas, both in each SVE well and the total flow passing through the vacuum blower. Comparison of the initial contaminant level spike to subsequent

rebound spikes is a useful tool for assessing the progress of SVE operations. Also, when determining whether to continue (or shutdown) SVE operations, the rebound spike data should be included in the assessment. This early stage is when the concentrations are most close to the equilibrium concentrations between the gas, sorbed and dissolved phases. Depending on precision, accuracy, and quantification requirements, vapor concentration measurements can be performed with field instruments or laboratory analyses. Field instruments include flame ionization detectors (FIDs), photoionization detectors (PIDs), combustible gas indicators (especially applicable to free phase LNAPL situations, where very high VOC concentrations in the extracted soil gas are expected) and colorimetric detector tubes. Total VOC measurements can be acquired with FIDs or PIDs. Although PIDs respond better to halogenated and aromatic hydrocarbons, FIDs provide a good response to most types of hydrocarbon contaminants. However, FIDs are less sensitive to the moisture that is usually present in the vapor stream. Whereas FIDs and PIDs can quantify only total VOCs, individual VOCs can be measured by gas chromatography combined with the appropriate detector, such as GC/FID, GC/PID, GC/MS, etc. Compound-specific identification and quantitation can be accomplished on samples collected in the field and brought to the laboratory, by having a field lab at the site, or by using portable GC instrumentation. Portable GC instruments generally have higher detection limits than laboratory GC instruments, but provide immediate data and can be much less expensive than bringing a field lab to a site. Sampling methods and holding times are an important consideration for laboratory analyses. Samples can be collected in specially manufactured sampling bags (i.e., Tedlar), evacuated canisters, or on activated carbon or other adsorption media. When using Tedlar bags, a sampling pump will be needed to overcome the vacuum in the pipes. Analytical methods and sampling procedures should be determined by the intended use of the data and should be in accordance with the project data quality objectives. Standards used for calibration of field instruments or GCs should be representative of the approximate composition of the target VOCs. If samples are collected for laboratory analysis of individual VOCs, measurements should be taken at the same time with the field instruments so that they can become better calibrated to actual site contamination distributions.

d. Extraction and Treatment Equipment Monitoring

(1) Once steady-state operation is achieved, operational efficiency data should be collected. With regard to an SVE system, steady-state operation will typically mean that all systems are running without shutdowns, the vapor treatment system is working and that flowrates have basically stabilized. VOC concentrations in the extracted vapor would not be expected to be stable. This manual is not intended to describe every potential component and its associated measurement criteria. However, several major components that need to be monitored will be common to almost all SVE/BV systems, including:

- Blowers/vacuum pumps.
- Air/water separators.
- Offgas treatment systems.
- Liquid pumps.
- Analytical and/or control instruments.

(a) Vacuum pumps and blowers – operational uptime and downtime should be continuously logged if possible. Opportunities for monitoring uptime include electronic hour meters, vacuum or pressure switches, or the instrumentation and control system if one exists. The pressure and vacuum being created by the blower can be monitored by recording the value on permanently mounted pressure gauges or by utilizing pressure transducers whose signal data can be stored by a datalogger or computer system. The gauge pressure should be measured on both the vacuum side and pressure side of the blower because they can be used with the manufacturer's blower curve to estimate the flow through the blower. Amperage meters on the blowers can also help to estimate the flowrate and monitor the performance of the blower motor. Temperature gauges should also record the temperature of the inlet soil gas and outlet temperatures. The total extracted soil gas flowrate, the flow through the blower, the inlet bleed valve, and the vapor treatment system, (the measurement methods were discussed in the proceeding section). The VOC concentrations in the total extracted soil vapor should be monitored at a frequency that will permit (along with the flow data) the total mass of contamination removed to be calculated. VOC concentrations are most reliably measured in the pressure side of the SVE system, so that the vapor sample does not have to collected (pumped) against a vacuum.

(b) Air/water (moisture) separators - Level meters or high and low level switches should be checked that they are operating properly so that water does not enter the blower (unless liquid ring pumps are used). Also filters should be checked frequently at startup due to the potential for dust, pipe shavings, and soil particulate to be pulled through the piping;

(c) Offgas treatment systems. – Maintaining the efficiency of the soil gas treatment system is important if air emission limits are to be continuously met. If granular activated carbon (GAC) treatment is used, concentrations should be measured in soil gas entering and exiting the units and between units if two or more vessels are used. Measurements can be made with the techniques discussed in the last section and usually consist of frequent measurements with a field instrument and periodic analysis by collecting samples for laboratory analysis. The observed mass loading rate of contaminants should be calculated to determine if the treatment system is sufficient to meet emission limits. The relative humidity of the soil gas to be treated may also need to be measured, or estimated. (As described in Chapter 5, high humidity reduces the adsorption capacity of the GAC and may need to be mitigated). The pressure drop through the GAC units should also be monitored to evaluate if the bed is becoming clogged and may need to be replaced, although this should not occur during the start-up phase. The temperature of the influent and effluent vapor streams are also important and can be used to monitor the amount of VOCs being destroyed by an thermal or catalytic oxidation system.

(d) Liquid (groundwater and or soil moisture condensate) pumps - If flows are low and condensate will be periodically removed and disposed of, the volumes can be noted in a field note book. If the condensate volume is high and is automatically pumped out and treated, a totalizer flow meter should be installed to record the total volume of groundwater/ soil vapor condensate removed. Alternatively, if an electronic pump control system is used, the flowrate information can be stored and processed. If the flowrate and contaminant concentrations in the moisture separator condensate are significant, the mass of contamination being removed may be significant enough that it should be quantified and reported as part of the remediation progress.

(e) Instrumentation and control devices should be calibrated as recommended by the manufacturer.

(2) Whether the above information is collected manually or electronically, a data management process must be established for operating components. Measurements should be made very frequently when operation begins and less frequently as the system equilibrates.

(3) It is imperative that "in-spec" and "out-of-spec" operating conditions be predetermined and listed on log sheets so that operators may detect potential problems early. It is equally important to identify

appropriate actions to be taken when "out-of-spec" conditions occur, including system shutdown, if necessary.

(4) All analytical and control instruments should be calibrated during the testing activities. Frequent checks (with results logged) and recalibrations (with results logged) of all instruments should be made during start-up to assure that proper control and analysis are occurring. This also establishes real-time reliability of the instruments.

(5) Once the initial data set is evaluated, system adjustments should be made and additional round of data collected until the system reaches a steady-state condition (as described earlier) wherein all design criteria are satisfied. At that point, start-up is complete.

7-5. Data Evaluation and Start-Up Report

a. Depending on the complexity of the system and the extent of the start-up testing program, a status report should be submitted after each phase or at the end of the start-up testing. It should include the checklist(s), including any outstanding "Actions Needed"; all data that was collected on the operating performance of any component or system, and the results of any failed tests along with a description of the corrective action taken. Full-scale continuous operation and transfer of the system to the owner or operator shall not occur until all planned start-up activities have been performed and approved.

b. The start-up report should contain the following information (if collected):

- Data tables of test observations (flow readings, vacuums/pressures, concentrations, levels, etc.);
- Influences (weather conditions, mechanical or electrical problems, total operation periods and duration);
- Predicted versus actual system performance (Figure 4-17 versus 7-1) and any differences between planned performance and actual results;
- Influent and effluent discharge concentrations from the soil gas vapor treatment system (Figure 7-1);
- Problem/incident reports;
- Vapor concentrations measured in individual SVE wells or vadose zone monitoring points;
- Oxygen, carbon dioxide levels measured in vadose zone monitoring points;
- Implications of actual start-up performance on full-scale remediation schedule;
- Soil vacuum/pressure distribution shown in cross-section and in plan view;
- Applied vacuum/pressure versus flow relations for individual SVE/BV wells and/or the entire SVE/BV system;
- Liquid recovery rates from the moisture separator;
- Corrective actions that have been taken during start-up, and potential problems that may need to be addressed during the operations and maintenance period.
- For each SVE well, plots of: volume of air extracted versus time, cumulate volume of air extracted versus time, concentrations or contaminants of concern versus time, mass removal rate of contaminants of concern versus time, and cumulative mass of contaminants of concern removed versus time.

- For the SVE system as a whole, plots of: concentrations or contaminants of concern versus time, mass removal rate of contaminants of concern versus time, and cumulative mass of contaminants of concern removed versus time.
-

c. Despite the available analytical and numerical models, actual vapor concentrations and recovery rates are difficult to predict prior to system operation, especially if the initial subsurface characterization was insufficient. Since these contaminant removal rates are directly related to the required treatment time, the achievable cleanup levels, and off-gas treatment requirements, actual recovery rates are a controlling factor for ultimate cleanup costs. Depending on how long the start-up period was and how much soil vapor concentration data was collected, it may be possible to get an initial indication of what can be expected by plotting extracted (individual SVE wells and/or total flow) concentrations versus time. Otherwise, this evaluation will take place during the operations and maintenance phase.

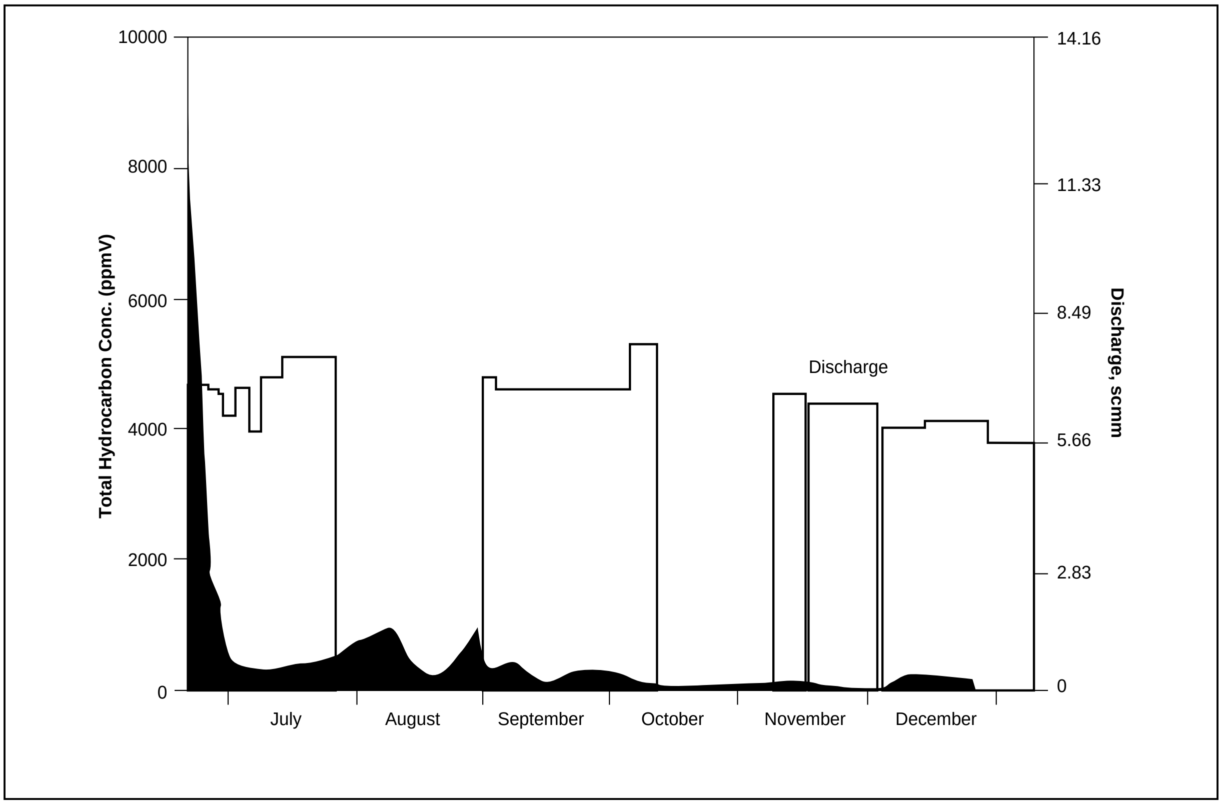

Figure 7-1. Total hydrocarbon concentration and extracted air flowrates over 6 months of SVE operation

d. As shown in Figure 7-1 extracted concentrations typically show an initial spike in concentration, followed by a rapid decline to a sustainable contaminant concentration ranging from 1 to 10 percent of the initial concentration. In Figure 7-1, the concentrations are shown as black shading and the flow rates are shown as lines. The concentrations drop rapidly over the first few days to a more sustainable rate. (It is important to remember that, if the vapor concentration in the total flow is measured after the blower and any dilution air is being let in, these measured concentrations must be corrected to represent the overall concentration being extracted from the soil.) Except for shut-down periods, the flow rate does not change appreciably in these examples.

e. Depending on how long the start-up period was and how much soil vapor flow and concentration data was collected, calculating the mass of contamination removed may or may not be possible. However, once sustainable concentrations have been achieved (during the start-up period or later in the Operations and Maintenance phase – discussed in Chapter 8), the actual contaminant mass removal rates can be calculated as illustrated in the example in Table 7-4**.** Table B-1, in Appendix B, presents the molecular weights of some most common VOC compounds, a value that must be known to complete the calculation. The results of these VOC mass removal rate calculations are typically presented as contaminant removal versus time (see Figure 7-2). Cumulative mass removal should also be plotted (refer to Figure 7-3). Using estimates of the original mass of soil contaminants, the estimated treatment time can be calculated assuming a gradual decline in the actual contaminant recovery rate. The results of these calculations may also be compared with the laboratory column test results described in paragraph 4-7a.

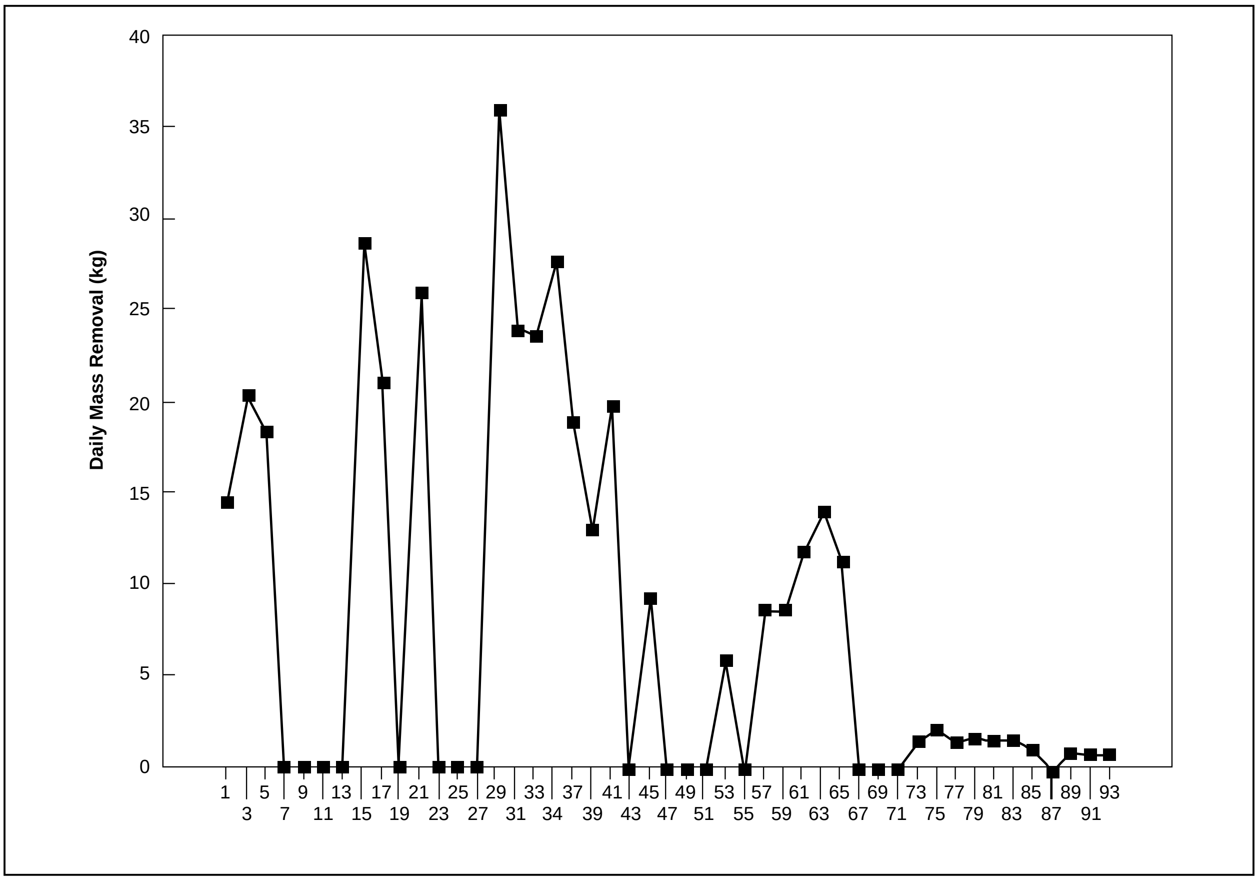

Figure 7-2 Daily contaminant removal

Table 7-4
Total Hydrocarbon Air Emission Calculations

ER = [(Q x C x MW x 2.68 x 10^{-3}) (kg/1000g)]

where

ER = emission rate (kg/hr)

Q = blower pumping rate (m3/min)

C = soil gas concentration (ppm-v)

MW = molecular weight of contaminant (g/g mole)

The constant (2.68 x 10^{-3}) has units of [(g-mole min)/m^3 ppm-v-hr)] and was derived in the following manner:

[(1/10^6 ppm-v) x (60 min/1 hr) x (1g-mole/0.0224 m^3)] = 2.68 X 10^{-3}

<u>CALCULATIONS</u>

Q = 7.08 m^3/min

C = 302 ppm-v (total hydrocarbons)

MW = 177 g/g mole (weathered gasoline, USEPA, 1991)

ER = [(7.08 x 302 x (1.77 x 10^2) x (2.68 x 10^{-3}) x 1/1000)]

ER = 1.01 Kg/hr

ER = 24.2 Kg/day

Source: after USEPA 1989d

The equation above is based on the following assumptions:

1) Standard temperature (0°C) and pressure (one atmosphere, or 760 mmHg)
2) Negligible change in air density
3) Constant concentration
4) Constant average molecular weight

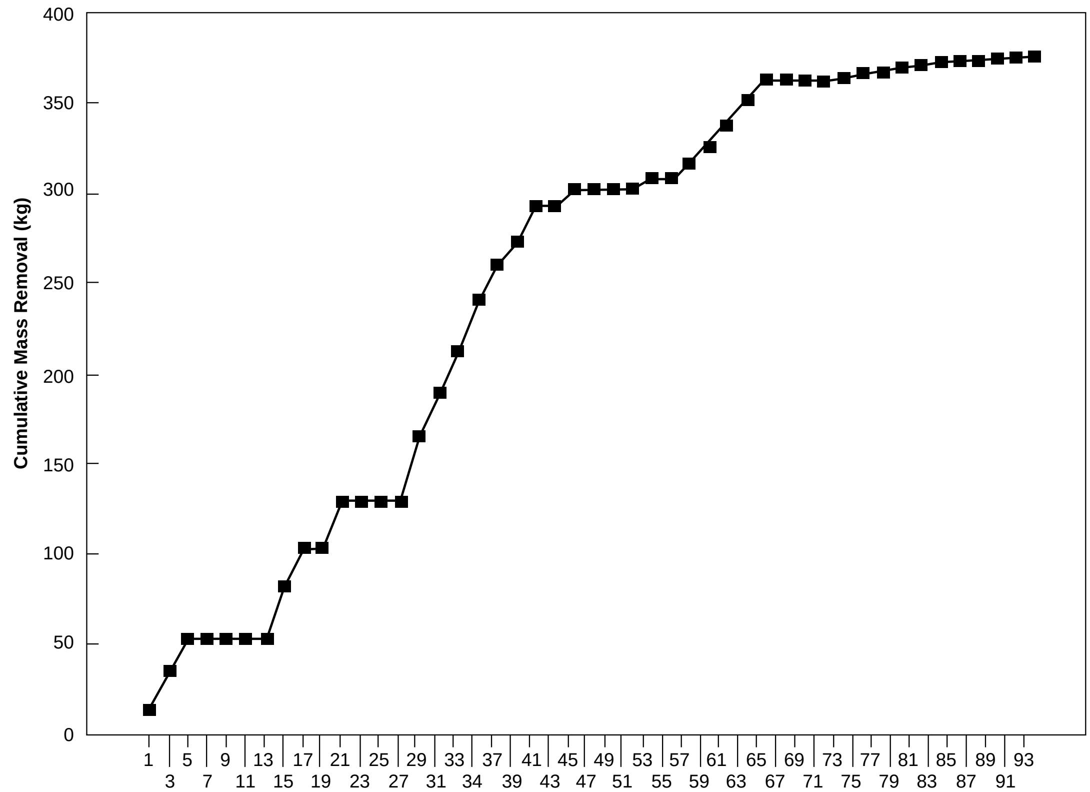

Figure 7-3 Cumulative contaminant removal